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Energy Procedia 37 (2013) 7318 – 7326
Energy Procedia

GHGT-11

Communicating CCS: Effects of text-only and text-and-visual depictions of CO_2 storage on risk perceptions and attitudes.

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Abstract

This experiment aims to increase understanding of the conditions under which combining textual and visual information on CO_2 storage fosters comprehension of the technology. Specifically, it is investigated if and how precision in indicating the depth of CO_2 injection in either text, visual, or combinations thereof influence estimates of CO_2 injection depth and how this in turn influences perceived safety of and attitude towards CO_2 injection. We used a 3x3 experimental design with two factors, resulting in 9 conditions: Textual description of depth of injection (absent, ambiguous, precise) X visualization of depth (absent, ambiguous, precise). Three texts were developed explaining the background and process of CCS. They were similar in every respect except for the accuracy of indication of depth: Absent ("underground"); Ambiguous ("deep underground"); Precise ("1,000 meters or deeper underground"). Three visual conditions were developed displaying the depth of CO_2 injection. They were similar in every respect except for the accuracy of indication of depth: Absent (no visual displayed); Ambiguous (visual not to scale, injection obviously too shallow); Precise (visual to scale). Respondents were a representative sample of the adult UK population (n = 429). Each of them received one of the nine conditions, followed by a short questionnaire. Results indicate that estimates of depth are generally most accurate in text-only conditions and least accurate in visual-only conditions. Interestingly, the condition in which people are given no information about depth at all scores in-between with a mean estimate of 869 meters. Regarding textual depictions of CO_2 injection depth, results indicate that the more precise indication of depth in the text the better respondents' estimate of depth, but this effect is only found for respondents who enjoy reading text. Regarding visual depictions of CO_2 injection, results indicate that the presence of a visual worsens respondents' estimate of depth, and the more precise indication of depth in the visual the worse respondents' estimate of depth. No relation was found between respondents' depth estimate of CO_2 injection and their attitude towards CCS and risk perceptions of CCS. However, a more positive attitude towards CCS was related to lower perceived risk. Explanations and implications for communication are discussed in the paper.

Keywords: CO_2 storage, Communication, Public understanding, Public attitudes

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Selection and/or peer-review under responsibility of GHGT
doi:10.1016/j.egypro.2013.06.670

1. Introduction

It is commonly assumed that information about complex topics such as new energy technologies or technical processes is easier to understand for a general audience when textual explanation is accompanied by visuals. Based on this assumption, advances in graphical technology have led to substantial investments in the creation of innovative, multimedia environments in which users can interact with information. Taking for example the process of CO_2 capture, transport and storage, companies take efforts to foster public understanding of this novel energy transition technology by providing imagery ranging from simple static overviews to animated, interactive three-dimensional depictions.

However, little is known about how any of such graphical representations actually influence information processing, understanding, and attitudes. Although research confirms that visuals can enhance understanding of a complex issue, it is not always well understood which elements of visuals sort which effect. Therefore, taking CO_2 injection as case, we designed an experiment that aims to increase understanding of the conditions under which combining textual and visual information fosters information processing about a complex, unfamiliar technology and how this in turn affects comprehension, risk perceptions, and attitudes.

An analysis of currently available visuals revealed that textual information about CO_2 injection is often accompanied by a visual that does not convey the same information. One example of such ‘incongruence’ is the depth of injection. In text often the precise depth will be mentioned, e.g. 1,000 meters. However, depth of injection is often visualized such that the CO_2 storage seems much closer to the surface, e.g. 10 meters rather than 1,000.† Observations from the field, e.g. at public meetings in Barendrecht (the Netherlands) where onshore CO_2 injection was being planned [1] indicate that not understanding depth of injection may induce worries about consequences of CO_2 leakage.

It is therefore important to investigate if estimates of depth are indeed related to perceptions about CCS such as the risk of leakage, and if so how information aiming to explain the depth of CO_2 injection to a lay audience should be designed to reduce these concerns. Does a precise indication of depth in either text of visual lead to a better depth estimate than a vague indication? Little is known about this, but we do know that preferences to process textual and visual information differ by individual. Some individuals prefer one over the other whereas others are equally good or bad at processing both types of information. These preferences may influence comprehension of textual and visual information and can be measured with verbalizing and visualizing scales. Central to this research are therefore the following questions:

(1) How does precision in indicating the depth in either the text or the visual influence estimates of injection depth?
(3) To what extent does estimated depth influence perceptions of the technology, in particular perceived safety and attitude towards CO_2 injection?

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† http://en.wikipedia.org/wiki/File:Carbon_sequestration-2009-10-07.svg

The following hypotheses are tested:
H1a The more precise the indication of depth in the text, the better the respondent's estimate of depth, in particular for those respondents who score highly on the verbalizing scale.
H1b The more precise the indication of depth in the visual, the better the respondent's estimate of depth, in particular for those respondents who score highly on the visualizing scale.
H2. The deeper respondents estimate the injection, the more positive their attitude towards CCS, the lower risk perceptions of CCS and the lower perceived personal relevance of CCS.

2. Method

2.1. Design and materials

To test whether accurate portrayal of scale in either textual information, visual information, or both makes a difference to people's understanding of the technology and their perceptions of CCS, we used a 3x3 experimental design with two factors. First, textual description of depth of injection (absent, ambiguous, precise). Second, visualisation of depth (absent, ambiguous, precise). This resulted in 9 conditions which are displayed in Table 1. Example stimuli are given in Appendix A.

Three textual conditions were developed explaining the background and process of CCS. They were similar in every respect except for the accuracy of indication of depth:

- Absent: only mentioning the storage is "underground"
- Ambiguous: containing a more vague description of the depth: "deep underground"
- Precise: stating the exact depth of storage: "1,000 meters or deeper underground.

Three visual conditions were developed displaying the depth of CO_2 injection. They were similar in every respect except for the accuracy of indication of depth:

- Absent: no visual displayed
- Ambiguous: injection obviously too shallow, indicated by familiar landmarks
- Precise: scaled visual – when measured with a ruler, injection is exactly 1,000 meters deep

To enable people to estimate depth, familiar landmarks were included: A tree, a car, and a power plant. One of the visuals showed depth of storage 'accurately' – assuming the power plant on the surface including the chimney is 50 meters high, onshore injection is exactly 1,000 meters deep. The other visual clearly shows depth 'inaccurately' which was achieved by inflating the landmarks and shortening the injection shaft. Since the experiment was conducted online, the stimuli were designed to fit 800*600 pixels to display properly on most computer monitors without requiring respondents to scroll.

Table 1. Experimental conditions.

	Textual indication		
Visual indication	Absent	Ambiguous	Precise
Absent	Both absent	Text-only	Text-only
Ambiguous	Visual-only	Both ambiguous	Precise/ambiguous
Precise	Visual-only	Ambiguous/Precise	Both precise

2.2. Respondents

A market research firm was hired to recruit a representative sample of subjects from the UK population in terms of age, sex, education, and region. 473 people participated in the research, however only 429 of them provided reliable responses. Of the respondents included in the analyses, 219 were males and 210 were females. Mean age was 41.77 (SD = 13.40) and ranged from 18-65. Respondents were tested on prior knowledge of CCS to control for effects on the results. No significant between-group differences were found in age, sex, education, region, or prior knowledge of CCS, thus ruling out these variables as alternative explanations for results.

2.3. Procedure

The experiment was conducted online and respondents could participate from their home computers. They first received the stimulus, which was followed by a short questionnaire. On average, the experiment took respondents 18 minutes to complete (SD = 52.50). At the start of the experiment, respondents were explained that the research aimed to investigate their opinion about a technology called carbon dioxide capture and storage (CCS). They were explained that they would be shown a section of a booklet about energy-related technologies containing a brief introduction to CCS (see Appendix A for examples). They were told that they could take as much time as they wanted to look at the information, but that to ensure some degree of exposure it would take 10 seconds for the <next> button to appear. As soon as the button appeared, respondents were able to go to the next screen and start the questionnaire.

2.4. Measures

2.4.1. Depth estimate

To check if manipulation of depth had succeeded, respondents were asked to estimate how deep (in meters) the CO_2 would be stored underground. The choice of meters was made because, even though British people are usually more familiar with feet for measuring everyday heights, meters are frequently used alongside feet in media outlets such as the BBC as well as in school science lessons. We can therefore assume that most respondents are familiar enough with meters, whereas feet are not very well understood by foreigners living within the UK.

2.4.2. Individual processing styles

Verbalizer scale. Preference for processing verbal information was measured with 4 items derived from an existing measurement instrument [2] e.g. “I enjoy doing work that requires the use of words”. The items formed a scale (Cronbach’s α = .80). To investigate the effect of a low versus high score on the verbalizer scale, respondents were divided into two approximately equally large groups whereby those scoring 2.25 or less were assigned to the ‘low’ verbalize group.

Visualizer scale. Preference for processing visual information was measured with 4 items derived from an existing measurement instrument [2] e.g. “I like newspaper articles that have photos”. The items formed a scale (Cronbach’s α = .63). To investigate the effect of a low versus high score on the visualizer scale, respondents were divided into two approximately equally large groups whereby those scoring 2.25 or less were assigned to the ‘low’ visualize group.

2.4.3. Perceptions of CCS

Attitude towards CCS. This was measured using 5 adjective pairs on a 7-point scale, e.g. 1 (positive) to 7 (negative). Respondents were asked to each time choose the description that best reflected their opinion about the information by clicking the response option close to that description. The adjective pairs formed a good scale (Cronbach's $\alpha = .89$).

Risk perceptions CCS were measured by giving respondents 8 statements about possible consequences of using CCS and by asking respondents to rate the likelihood of these consequences, e.g. "CO_2 will acidify the underground drinking water". Of these items, which were all measured on a 5-point scale, 7 formed a good scale (Cronbach's $\alpha = .84$) and were combined. The item that did not scale, "The safety of a CO_2 storage site can be sufficiently guaranteed", was analyzed separately and was labeled *Safety CCS*. The item was recoded to make a higher score represent stronger disagreement with the statement similar to the other risk perception statements.

Personal relevance of CCS was measured with the items "Would you mind if a CCS project was planned in the area where you live?" (1 = very much to 5 = not at all) and "Do you think plans for CCS in your area would have a positive or negative impact on your area?" (1 = very negative to 5 = very positive). The items did not form one scale. Therefore, minding CCS in the area and estimating the impact of CCS in the area were analyzed separately and labeled *CCS in area* and *Impact CCS*, respectively.

3. Results

3.1. Estimates of injection depth

Table 2 shows the mean depth estimates per condition. A pattern can be observed: estimates of depth are most accurate in text-only conditions and least accurate in visual-only conditions. A GLM comparing text-only with visual-only conditions reveals a significant difference, $F(1,190) = 17.52$, $p < .001$, Eta Squared = .08. The third-deepest estimate is made by respondents receiving precise textual and ambiguous visual information whereas the third-shallowest estimate is made by respondents receiving precise textual and precise visual information.

One explanation for this is that people do notice when a visual is or is not to scale. When it is not to scale, they will rely on textual information. When it is to scale, they will try to base their depth estimate on visual information but get it wrong, resulting in worse estimates even when there is a depth indication in the text as well. Apparently the landmarks do not help people – the car and tree are too small and the power station is not estimated to be at least 50 meters high but smaller. Interestingly, Table 2 shows that when people are given no estimate of depth at all their mean estimate is 869.33 which is pretty good. Apparently, offering information about depth of injections will in some cases negatively affect depth estimates. Below we explore this further.

Table 2. Mean estimates of meters per condition

	Textual indication		
Visual indication	Absent	Ambiguous	Precise
Absent	869.3	1355.5	1336.8
Ambiguous	663.6	786.6	1096.7
Precise	557.2	837.3	741.1

3.2. Hypotheses testing

H1a The more precise indication of depth in the text the better respondents' estimate of depth, in particular for those respondents who score high on the verbalizing scale.

To check for main effects of text, a variable with 3 values was created: Value 1 was assigned to conditions in which a textual indication of depth was absent; value 2 to conditions in which the textual indication was ambiguous; value 3 to conditions in which the textual indication was precise. Running a GLM a significant main effect of text was found, $F(2,419) = 4.87$, $p = .01$, Eta squared = .02. A precise text leads to the deepest estimate of depth in meters, followed by an ambiguous text, followed by absence of depth indication in text. The post-hoc test did not reveal a significant difference between the precise (1057.40) and ambiguous (997.76) indication, but both conditions differed significantly from the condition in which indication of depth was absent (700.37), $p = .05$.

In addition a significant interaction effect was found with the verbalizer scale, $F(2, 419) = 4.64$, $p = .01$. The found main effect of textual preciseness is only found for high verbalizers. Low verbalizers estimate the depth of injection the deepest when presented an ambiguous text, followed by a precise text. Furthermore, when presented a precise text, which explicitly states that depth of injection is 1,000 meters or lower, low verbalizers still estimate depth on average below 1,000 meters ($M = 973.02$, $SD = 121.288$). These results indicate that low verbalizers have processed the textual information less carefully, as their low score on this scale would predict. No significant interaction effect was found with the visualizer scale, $F(2,419) = .58$, ns.

This means that H1a is accepted. The more precise indication of depth in the text the better respondents' estimate of depth, however this effect is only found for respondents who score high on the verbalizing scale.

H1b The more precise indication of depth in the visual the better respondents' estimate of depth, in particular for those respondents who score high on the visualizing scale.

To check for main effects of visual information, a variable with 3 values was created: Value 1 was assigned to conditions in which a visual was absent; value 2 to conditions in which the visual was ambiguous; value 3 to conditions in which the visual was precise. Running a GLM a significant main effect of visual was found, $F(2, 419) = 6.54$, $p = .00$, Eta squared = .03. A precise visual leads to the shallowest estimate of depth in meters, followed by an ambiguous visual, followed by absence of visual information. Post-hoc tests revealed that the absence of a visual leads to significantly deeper estimates (1181.62) than the presence of either an ambiguous (853.49) or precise (712.58) visual, $p = .05$.

In addition, we investigated possible interaction effects between visual depth indication and processing style. No significant interaction effects were found with either the verbalizer scale, $F(2, 419) = 1.45$, ns or the visualizer scale, $F(2,419) = .71$, ns.

This means that H1b is rejected. The presence of a visual worsens respondents' estimate of depth, and the more precise indication of depth in the visual the worse respondents' estimate of depth. This effect is independent of processing style.

H2. The deeper respondents estimate the injection, the more positive their attitude towards CCS, the lower risk perceptions of CCS and the lower perceived personal relevance of CCS.

Correlational analyses were performed to relate estimates of depth to attitude, risk perceptions of CCS and perceived personal relevance of CCS. Results are displayed in Table 3 along with the Means (M) and Standard Deviations (SD) per variable. With correlations between Depth estimate and the other variables varying between -.04 and .08 we have to conclude that depth estimates on the one hand and attitude towards CCS, risk estimates, and perceived personal relevance are completely unrelated.

Table 3. Values and correlations for variables relating depth to attitude, risk perceptions and perceived personal relevance.

	Mean	SD	1	2	3	4	5
1.Estimate of depth	915	1161					
2.Attitude CCS utility and safety	3.64	0.84	.08				
3.CCS in area	3.07	1.22	.07	.53			
4.Impact CCS	2.83	1.15	-.04	.50	.45		
5.Risk perception CCS	2.96	0.75	.02	-.38	-.50	-.17	
6.Safety CCS	3.15	1.01	-.04	-.50	-.41	-.48	.24

Looking at the correlations between the dependent variables, significant correlations are observed between attitude towards CCS and perceived personal relevance. The more positive people's attitudes the less negative they respond to the idea of having a CCS project nearby. Furthermore, the more positive people's attitudes towards CCS, the less negative impact they expect of a project nearby. A more positive attitude and a lower personal relevance are also significantly related to a lower perceived risk of CCS.

This means that H2 is rejected. Respondents' depth estimate of CO_2 injection of is unrelated to their attitude towards CCS, risk perceptions of CCS, and to perceived personal relevance of CCS. However, a more positive attitude towards CCS is related to less perceived risk and lower personal relevance.

4. Discussion

4.1. Explanation of findings

The main effect of textual information on people who score high on the verbalizing scale is easy to understand: In the absence of indication in the text it is entirely up to the respondent to figure out how deep the injection is. If it is stated that the underground storage is 'deep' that gives some idea, but a specific number obviously gives the best indication. This, however, apparently only makes a difference for respondents who score high on the verbalizing scale which indicates they enjoy processing texts. For respondents who do not particularly enjoy processing texts, a more precise depth indication in text does not necessarily lead to a better depth estimate. This implies that it will not necessarily be of help to everybody if a text communicates how deep the injection is – this is only helpful to those who like to read. Fortunately, the data also show that people usually are already very good at estimating depth when clues in text are absent. We did not find that visual information improves respondents' estimate of depth, whether they score high on the visualizing scale or not. On the contrary, visual information can apparently be confusing. Present results have shown that a visual, whether accurately or inaccurately scaled, leads to worse estimates of depth than the absence of a visual. Possible explanations are:

- In the absence of a visual, people logically fall back upon the text, and their depth assessment depends upon it. This explains why text-only presentation leads to the best estimates.
- When the text is accurate but the visual is ambiguous, it will be clear to most people that the scale is incorrect. Assuming that most people correctly take the picture to be a schematic overview, they will largely ignore the depth indication in the visual and will rely on the textual information to make a depth estimate. This explains why the third best estimate was made in the precise text / visual ambiguous condition. By contrast, the combination precise visual / precise text leads to the third worst depth assessment. Apparently people think the visual is accurate, but they do not read an injection depth of 1,000 meters in it. Further research is recommended: A question could be added to determine whether people see the picture as "schematic" or representing "true proportions".

- When a text lacks a depth indicator and people have to base their interpretation on the visual alone, then we see that a properly scaled image leads to a relatively shallow assessment. In an ambiguous picture that effect is slightly less bad. The estimate based on an image is between 500 and 700 meters. Apparently, people estimate the power station shown in the visual lower than 50 meters.
- The experimental manipulation was not strong enough. When the visual is printed out and measured with a ruler, then the CO2 is indeed 1,000 meters deep when you assume the plant including chimney is 50 meter high. However many people may not know how high a factory is, and a car and a tree may be too small. To enhance the visual, it possibly should have displayed a ruler. Trees or factories could then be placed next to the ruler to give additional clarity on height.

4.2. Implications for communication

The results of the study lead to some tentative recommendation for communication. We cannot assume that people correctly interpret a chart or diagram, whether or not to scale. Charts and diagrams are suitable to demonstrate the technical process to people, but visualizing how deep CO_2 is stored in a way that people will understand is difficult. Findings from the present experiment suggest that this is hardly worth the effort – get it wrong and depth estimates will worsen. It is much easier and much more effective to mention depth of injection in text, bearing in mind that this will be only improve the understanding of depth for some people whereas on others it will have no effect.

Should communicators about CCS fear after reading these results that particular combinations of textual and visual information in use by their company may induce wrong depth estimates, remember the conclusion from this experiment that respondents' depth estimate of the injection of CO_2 is unrelated to their attitude towards CCS, risk perceptions of CCS, and to perceived personal relevance of CCS. A more positive attitude towards CCS is related to less perceived risk and lower personal relevance, but attitude is apparently unrelated to how deep people think the CO_2 is put underground.

Depth of injection was central to the present experiment because it was thought, based on previous observations in a.o. Barendrecht, that this may affect risk perceptions and attitudes. Present findings do not demonstrate such a relation. It remains an interesting topic for future research if and how correctly knowing about aspects of CCS does relate to risk perceptions and attitudes.

Acknowledgements

The authors thank Kenshi Itaoka and Aya Saito from the Mizuho Information and Research Institute for giving us permission to use their visual as a basis for this experiment.

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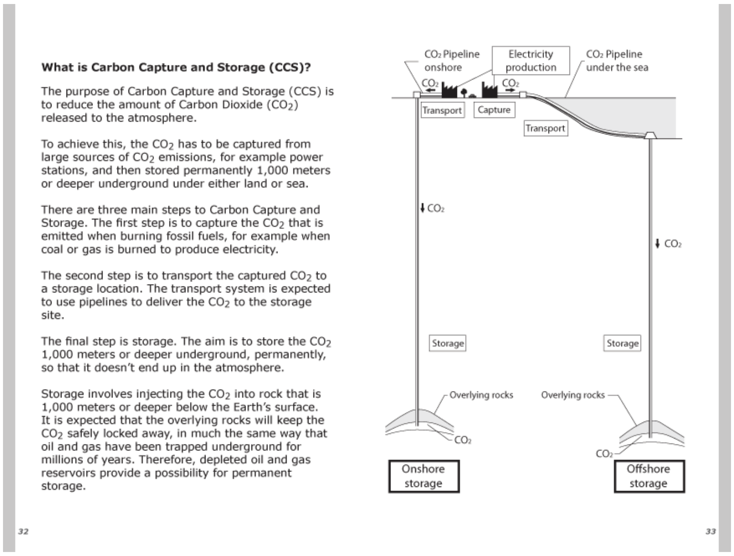
Appendix A. Examples of stimulus materials.

A.1. Condition 6 – Textual indication precise, Visual indication precise.



What is Carbon Capture and Storage (CCS)?

The purpose of Carbon Capture and Storage (CCS) is to reduce the amount of Carbon Dioxide (CO_2) released to the atmosphere.

To achieve this, the CO_2 has to be captured from large sources of CO_2 emissions, for example power stations, and then stored permanently 1,000 meters or deeper underground under either land or sea.

There are three main steps to Carbon Capture and Storage. The first step is to capture the CO_2 that is emitted when burning fossil fuels, for example when coal or gas is burned to produce electricity.

The second step is to transport the captured CO_2 to a storage location. The transport system is expected to use pipelines to deliver the CO_2 to the storage site.

The final step is storage. The aim is to store the CO_2 1,000 meters or deeper underground, permanently, so that it doesn't end up in the atmosphere.

Storage involves injecting the CO_2 into rock that is 1,000 meters or deeper below the Earth's surface. It is expected that the overlying rocks will keep the CO_2 safely locked away, in much the same way that oil and gas have been trapped underground for millions of years. Therefore, depleted oil and gas reservoirs provide a possibility for permanent storage.

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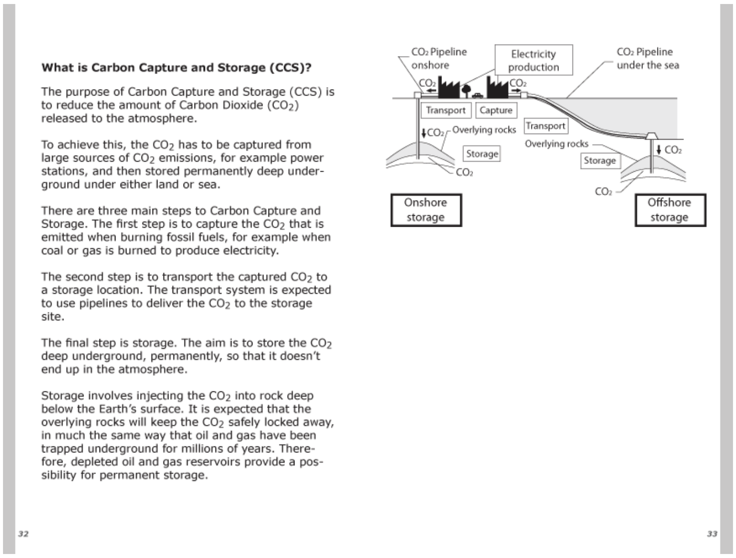
A.2. Condition 6 – Textual indication ambiguous, Visual indication ambiguous.



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